How special are Brightest Cluster Galaxies?

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in many clusters:

- central, dominant (elliptical) galaxy
  $\longrightarrow$ "brightest cluster galaxy" (BCG)

some BCGs:

- cD galaxies (extended envelope)

but not every BCG is a cD galaxy!

What drives the properties of BCGs?

- stellar mass?
- location in cluster center?

cD galaxies:

- often host radio–loud AGN (Burns 1990)
- lie on Fundamental Plane (Oegerle & Hoessel 1991)
- do not lie on Faber–Jackson relation (Oegerle & Hoessel 1991)

Environment at cluster core:

- depth of potential well $\leftrightarrow$ dark matter
- hot gas
- cooling flow ?

Formation mechanism:

- stars form early ($z_{\rm form} \sim 2-5$) in many small galaxies
- BCGs assemble late via merging

$\rightarrow$ *dry mergers*

(de Lucia & Blaizot 2006; Boylan–Kolchin et al. 2006)

Aim:

- disentangle influences from stellar mass and cluster environment

Strategy:

- compare BCGs to non–BCGs of similar stellar mass

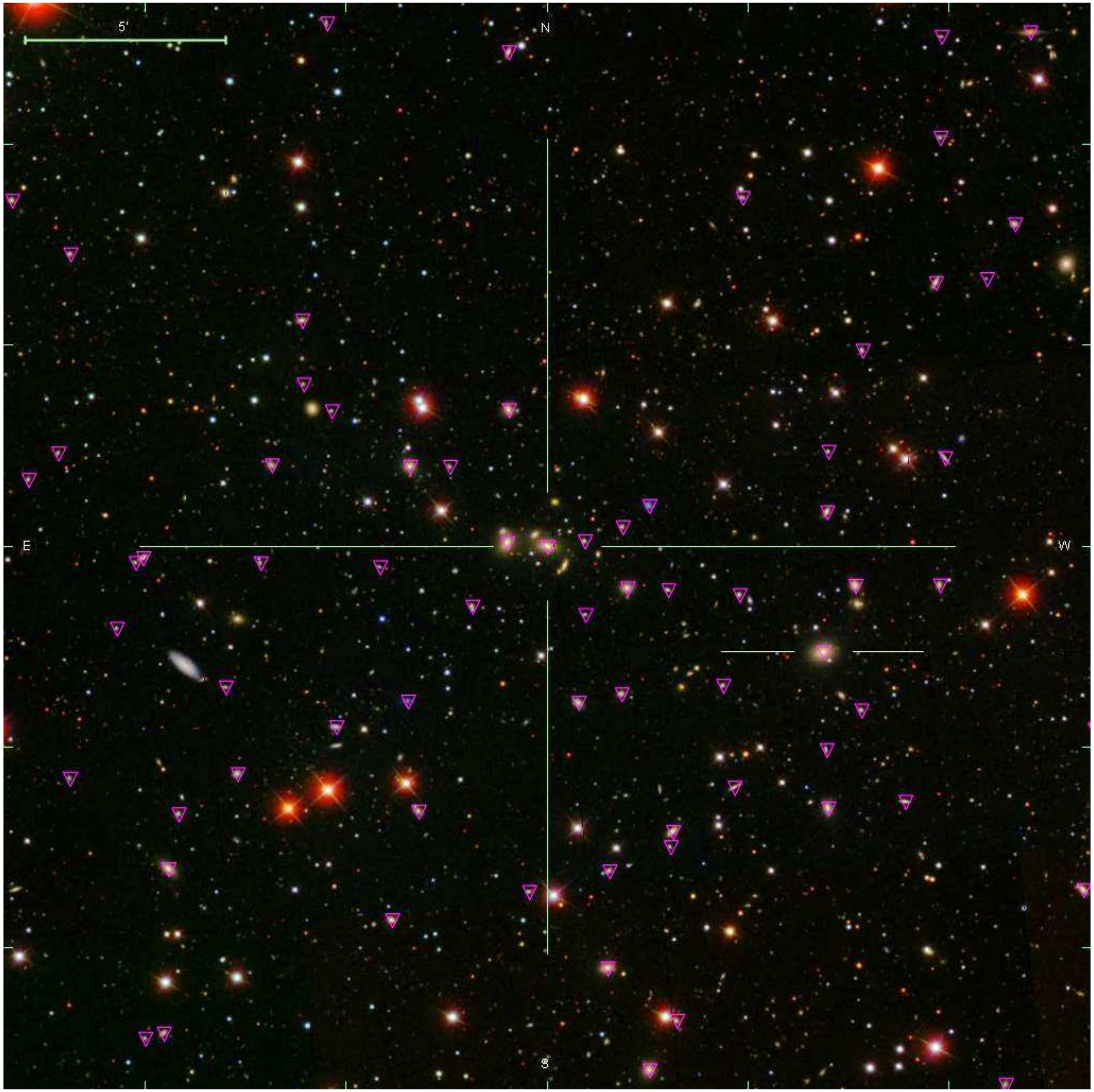
Data:

- need large, homogeneous dataset
  $\longrightarrow$ Sloan Digital Sky Survey (SDSS)

Basis of cluster sample: the C4 catalog

- C. Miller, R. Nichol, et al., 2005
- cluster identification in position, redshift, and color space
  $\rightarrow$ assumption: cluster galaxies have similar colors
- public version: based on DR2, 748 clusters, $0.02 < z < 0.17$
- SDSS-internal version: based on DR3, 1106 clusters, $0.02 < z < 0.17$
- based on spectroscopic catalog only
  $\rightarrow$ $\sim$30% of BCGs missed due to fiber collisions

Choice of BCG – central galaxy



1. redshift limit $z \leq 0.1$ (833 clusters)
2. determine BCG:
   - draw candidates (C4 BCG(s), bright E's in vicinity of cluster center)
   - eye-ball candidates, choose BCG
3. identify clusters associated with identical BCG (732 clusters)

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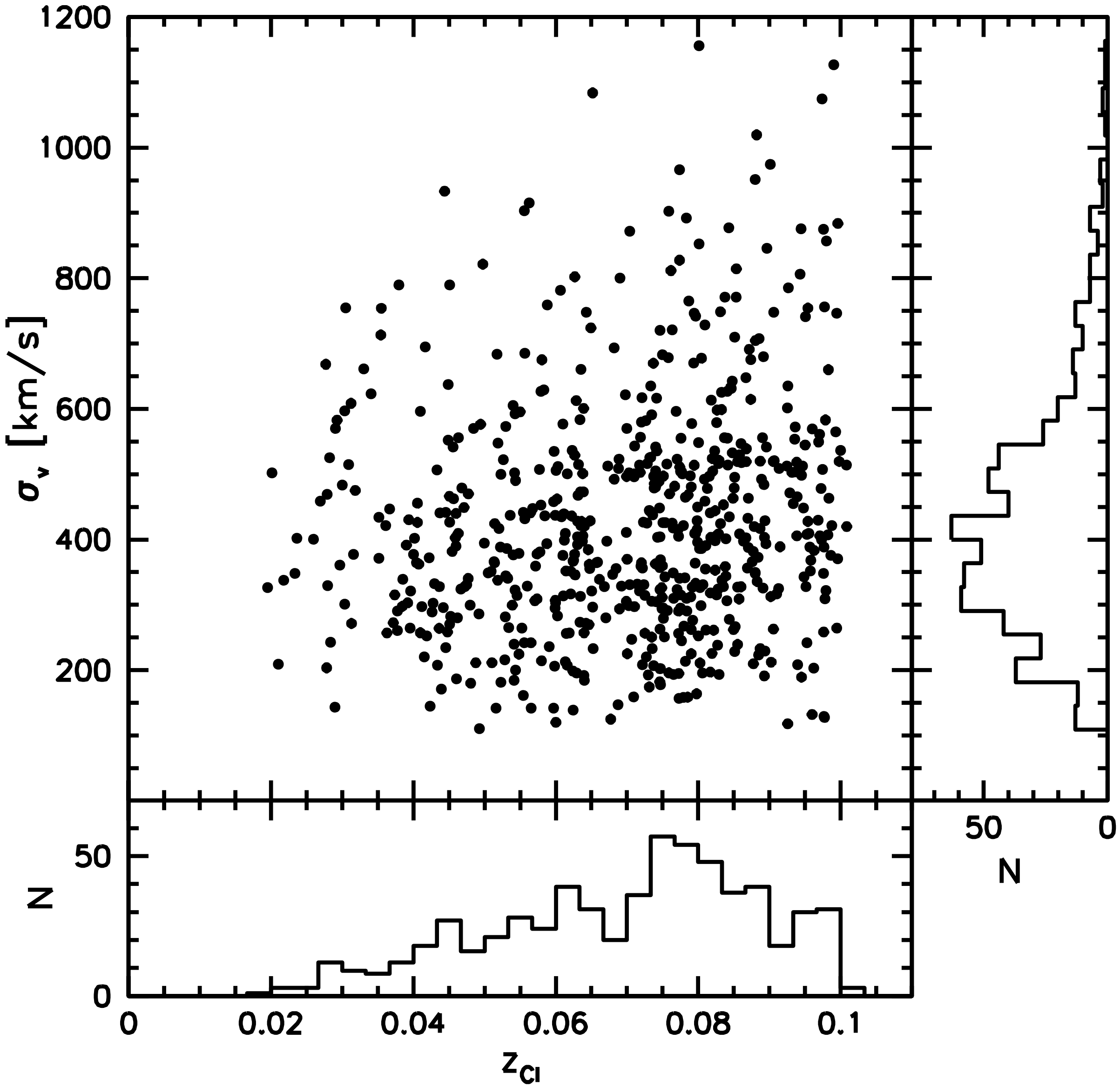
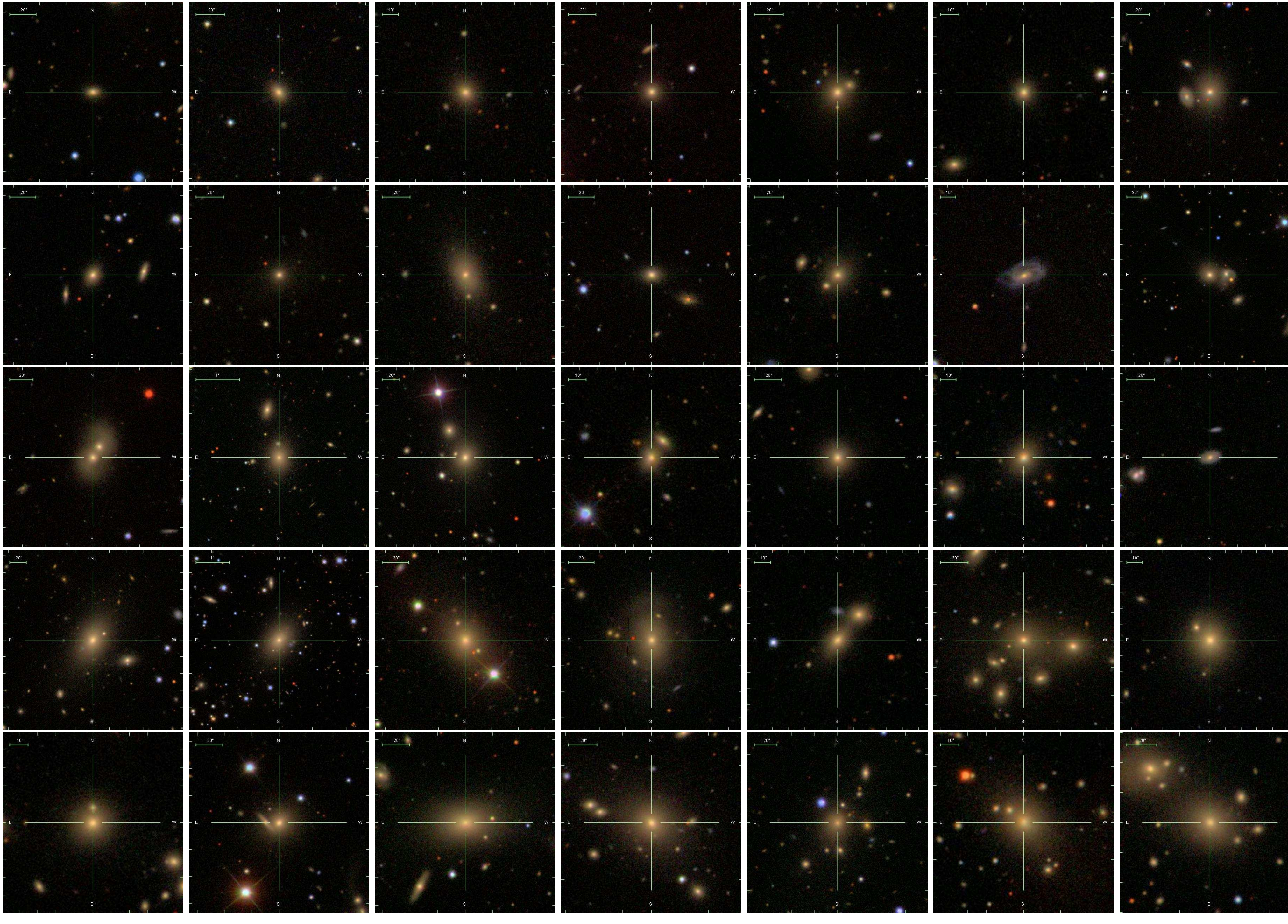
3. identify clusters associated with identical BCG (732 clusters)
4. determine redshift, velocity dispersion σ_v, R_{200}, cluster members iteratively (677 clusters):
   - initial redshift as given by C4
   - initial $\sigma_v \leq 500$km/s
   - cluster members within $\pm 3\sigma_v$ and R_{200}
5. visual inspection (642 clusters)
6. $N_{\rm galaxies} \geq 4$ (625 clusters)


1200
1000
800
600
400
200
σ_v [km/s]
N
50
0
0
0.02
0.04
0.06
0.08
0.1
z_Cl
50
0
N



Magnitudes and Masses

SDSS photo pipeline underestimates luminosities of large galaxies (e.g. local BCGs)

$\longrightarrow$ "patch" to derive more accurate luminosities from 1D surface brightness profiles (catalogued)
add fraction (up to 70%) of difference in `local` and `global` sky background

isophotal magnitudes:

- no assumption on profile shape
- isophote limit $23\,r - \mathrm{mag}/\square''$
- cD envelope not included
- intracluster light not included
- avoids residual sky subtraction problems
- stellar masses via `kcorrect` (Blanton & Roweis 2006)

Comparison samples

comparison samples matched in $M_\star$, z, and $g - r$

for general comparison:

- 3 non–BCGs per BCG with $\log(M_\star/M_\odot) < 11.3$

for scaling relations:

- 1 non–BCG per early–type BCG

Again - what are these?

BCGs:

- brightest galaxy in the center of the clustering
- $\sim$ 85% are the brightest galaxy in the cluster $(1R_{200},\ \pm 3\sigma_{\rm v})$
- $\sim$ 50% in galaxy groups with $\sigma_{\rm v} \lesssim 400$ km/s

non–BCGs:

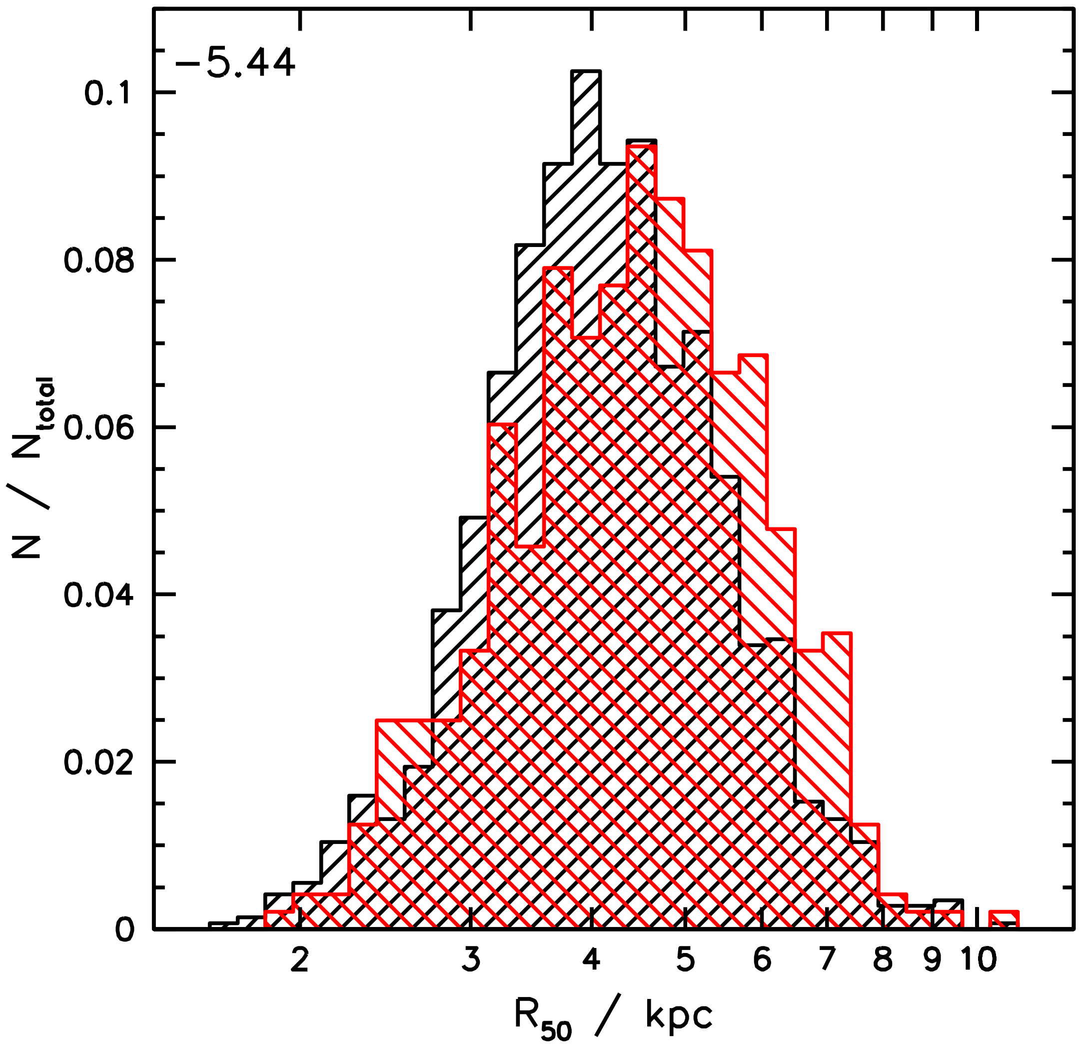
- anything else

quoted stellar masses:

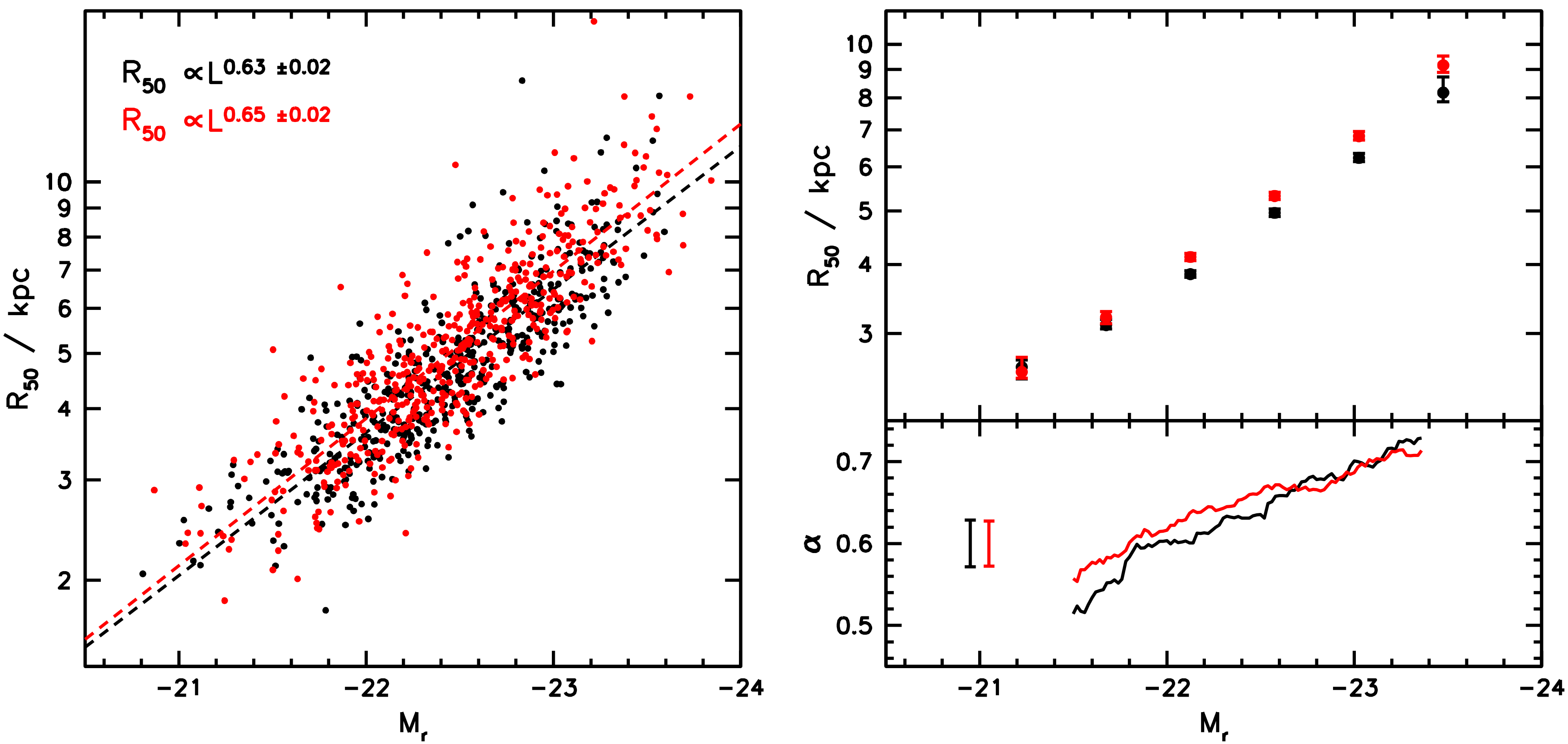
- based on isophotal $ugriz$ photometry
- cD envelope not included

Results

- **BCGs are larger**

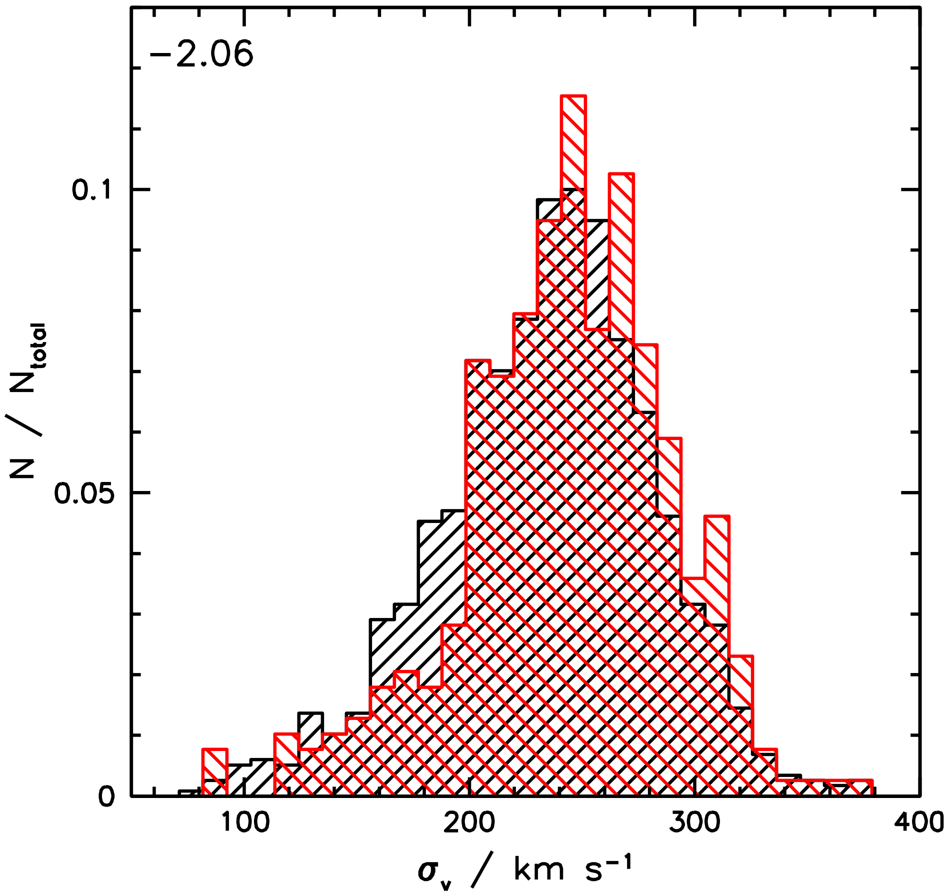


- size–luminosity relation $R_{50} \propto L^{\alpha}$: slope similar for BCGs, steepening at massive end



Results

- BCGs are larger
- **BCGs have higher velocity dispersions**



- radius, velocity dispersion $\longrightarrow$ dynamical mass
- virial theorem

$$M_{\mathrm{dyn}} = \frac{\sigma_{\mathrm{v}}^2 \, R}{G}$$

- radius, velocity dispersion $\longrightarrow$ dynamical mass
- virial theorem , projected onto observables

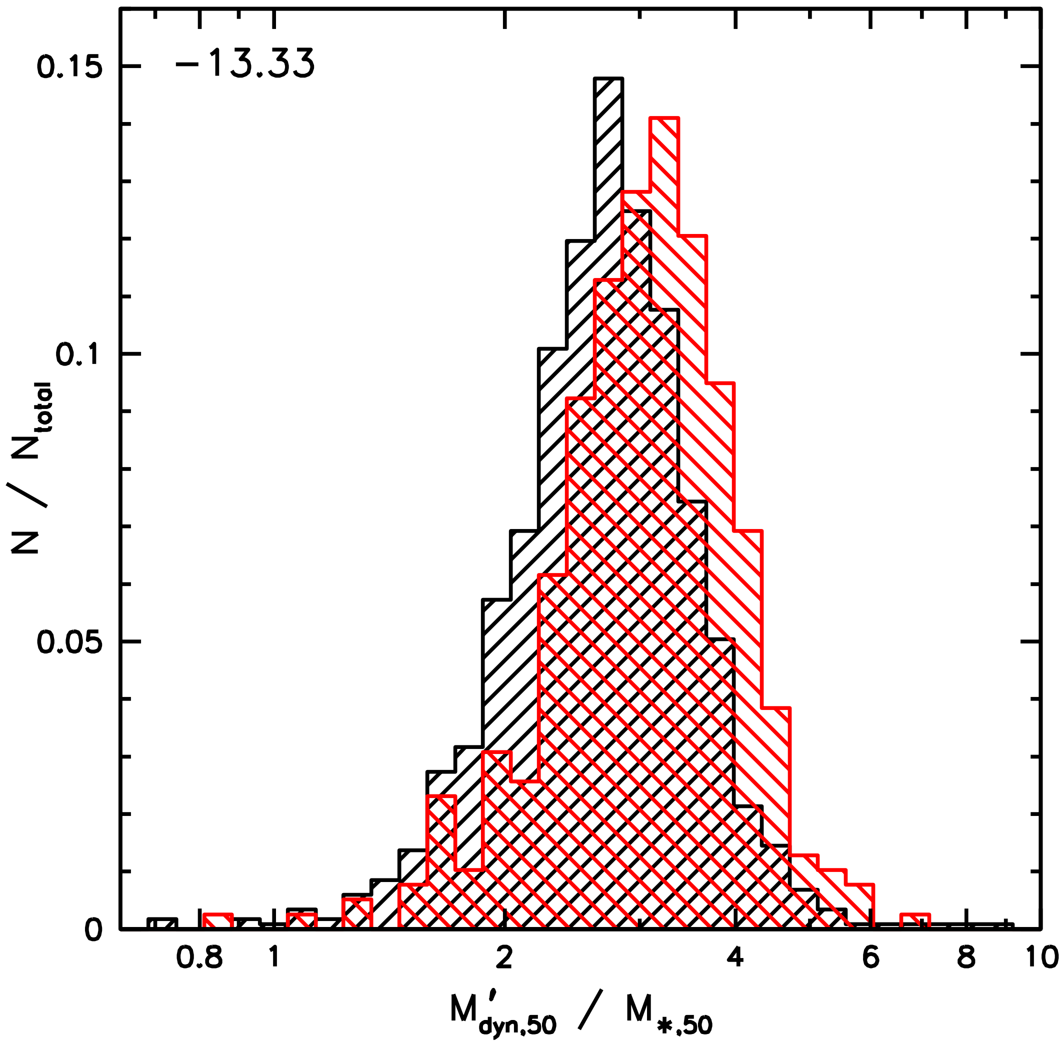
$$M_{\mathrm{dyn},50} = c_2 \frac{\sigma_{\mathrm{v}}^2 R_{50}}{G}$$

- c_2 depends on distribution of dark matter and stellar halos

$$\left.\begin{array}{l}\text{DM: NFW profile}\\ \text{stars: Hernquist profile}\end{array}\right\} c_2 = (1.65)^2$$

Results

- **BCGs have higher dark matter fractions**



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$$
\begin{aligned}
M_{\mathrm{dyn},50} &= c_2 \frac{\sigma_{\mathrm{v}}^2 \, R_{50}}{G} \\
M_\star &= c_1 L \\
L/2 &= \pi R_{50}^2 \, I_{50}
\end{aligned}
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\Longrightarrow \quad R_{50} &= \frac{1}{2\pi G} \frac{c_2}{c_1} \frac{M_\star}{M_{\mathrm{dyn},50}} \sigma_{\mathrm{v}}^2 \frac{1}{I_{50}}
\end{aligned}
$$

Fundamental Plane: $R_{50} \propto \sigma_{\mathrm{v}}^a I_{50}^{-b}$

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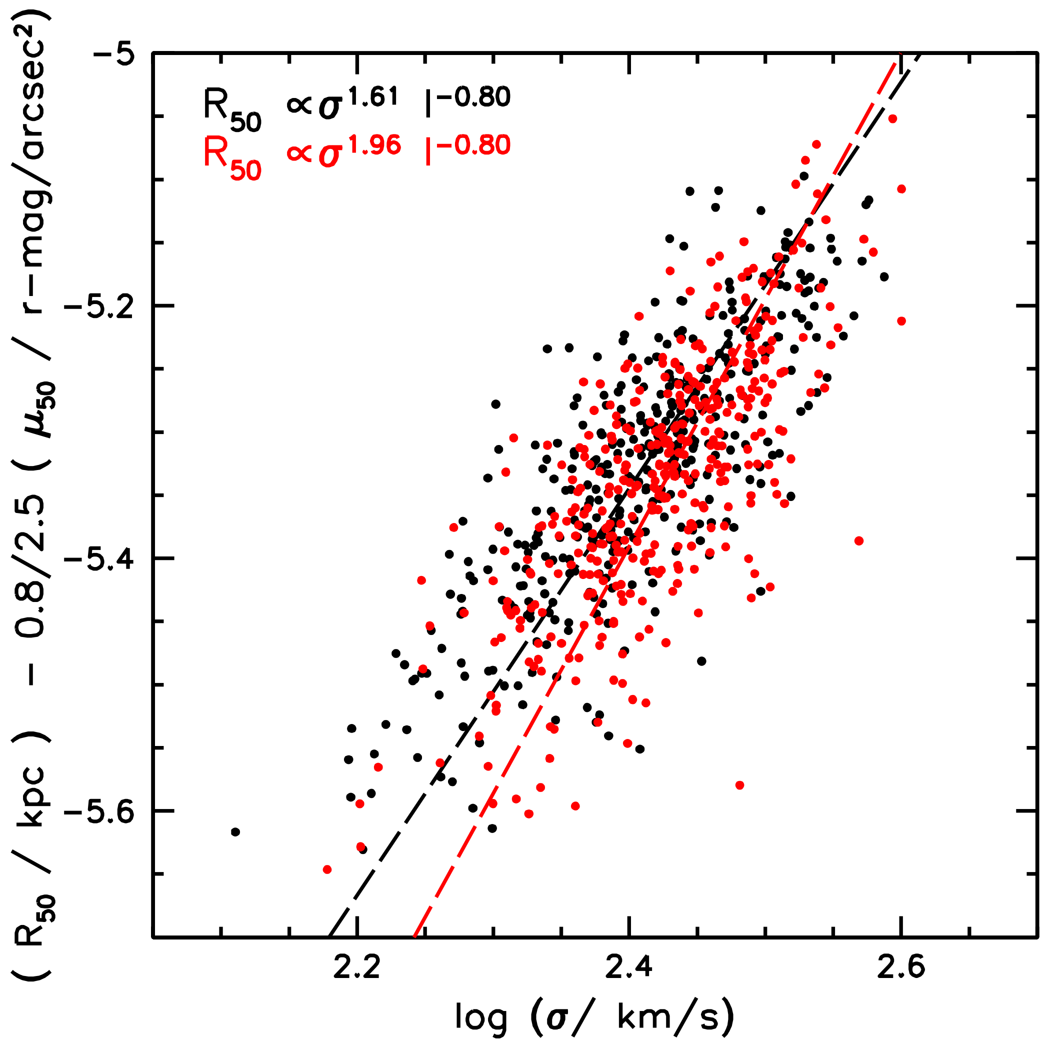
\text{Fundamental Plane:} \quad R_{50} &\propto \sigma_{\mathrm{v}}^a I_{50}^{-b} \\
\text{virial FP:} \quad \frac{c_2}{c_1} \frac{M_\star}{M_{\mathrm{dyn},50}} &= \text{const} \\
\Leftrightarrow \quad & \quad a = 2,\ b = 1 \\
\text{observed:} \quad & \quad a \sim 1.2 - 1.6,\ b \sim 0.8 \quad \text{“tilt”}
\end{aligned}
$$



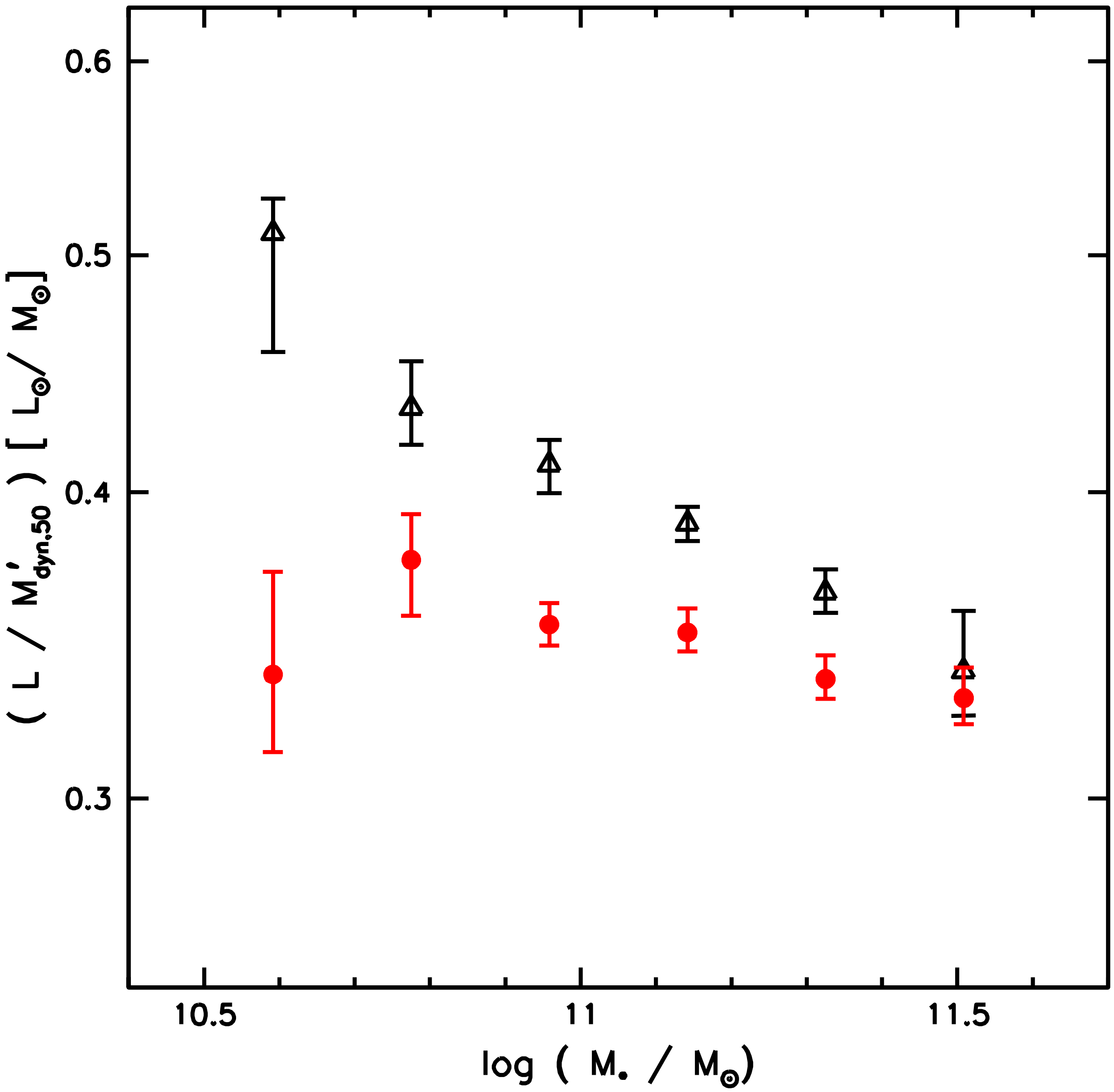
symmetric fit, $b \equiv 0.8$

$$a_{\mathrm{non-BCGs}} = 1.61 \pm 0.07$$
$$a_{\mathrm{BCGs}} = 1.96 \pm 0.10$$

BCGs closer to virial FP

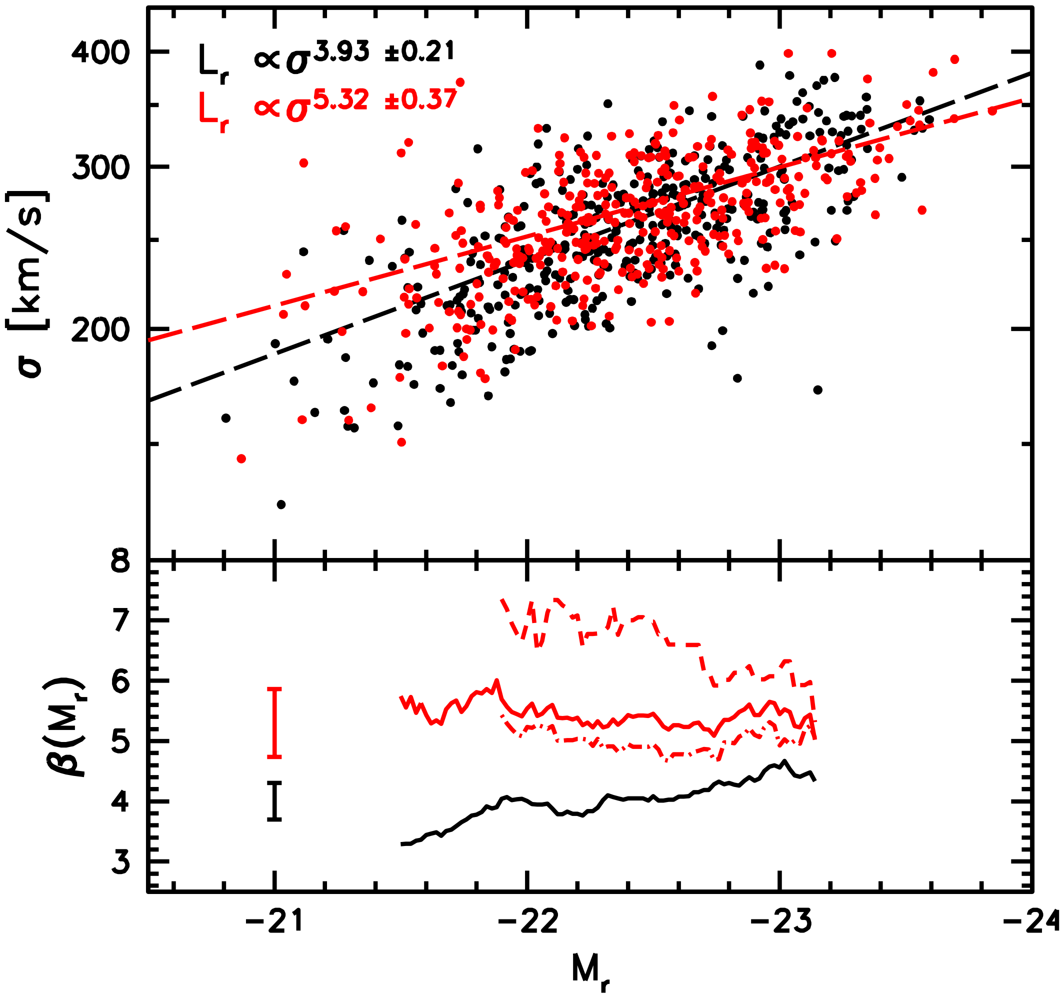
difference must be in

$$\frac{c_2}{c_1} \frac{M_\star}{M_{\mathrm{dyn},50}} = \frac{L}{M_{\mathrm{dyn},50}/c_2}$$



0.6
0.5
0.4
0.3
10.5
11
11.5
log (M. / M⊙)
(L / M'dyn,50) [L⊙/ M⊙]

- Faber–Jackson relation: $L \propto \sigma^\beta$



$$\beta_{\text{non-BCGs}} = 3.93 \pm 0.21$$
$$\beta_{\text{BCGs}} = 5.32 \pm 0.37$$

dry merger simulations: β increases with eccentricity of merger orbit

(Boylan–Kolchin et al. 2006)

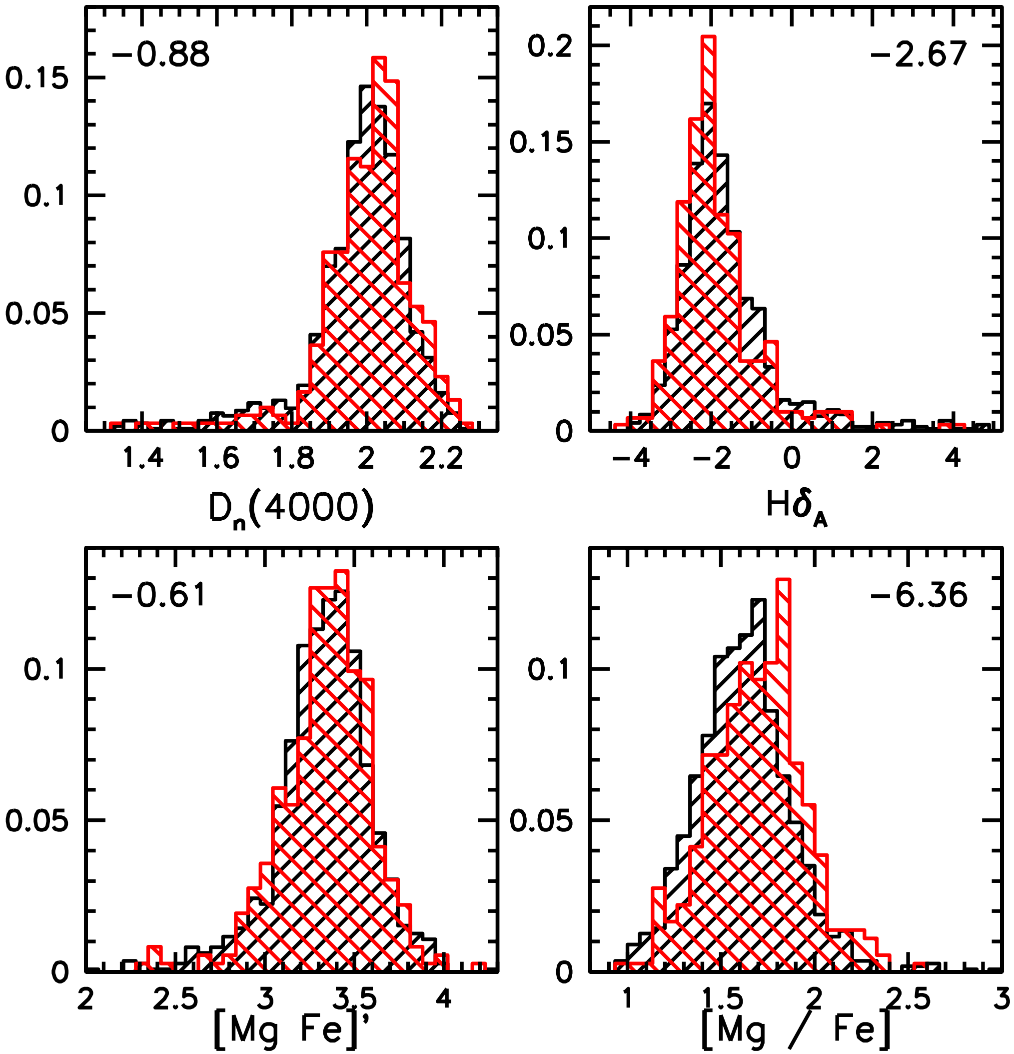
Results

BCGs . . .

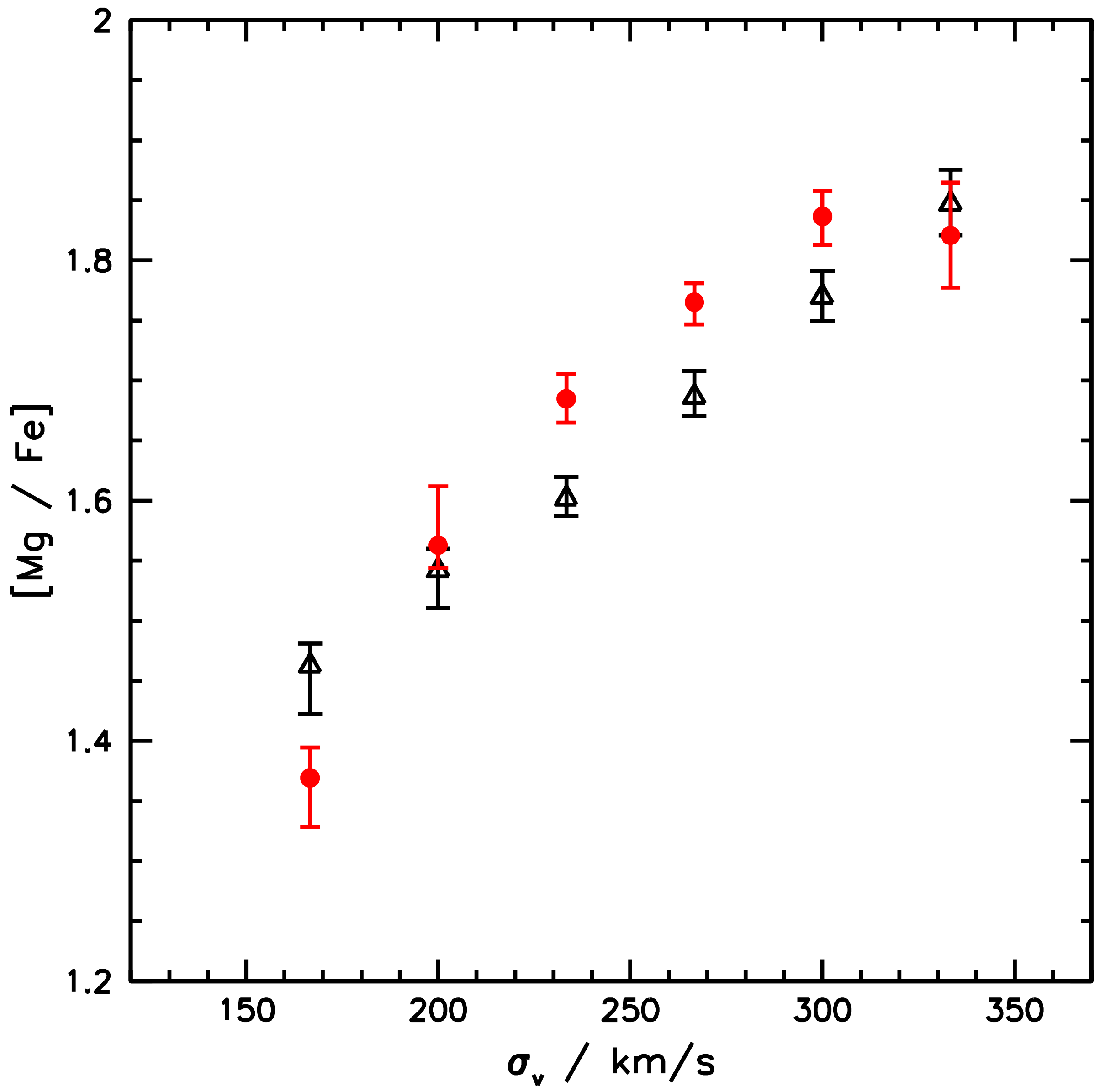
- are larger
- have higher velocity dispersions
- have higher dark–matter fractions
- **lie on a different Fundamental Plane**
- **lie on a steeper Faber–Jackson relation**

. . . than non–BCGs

Stellar populations

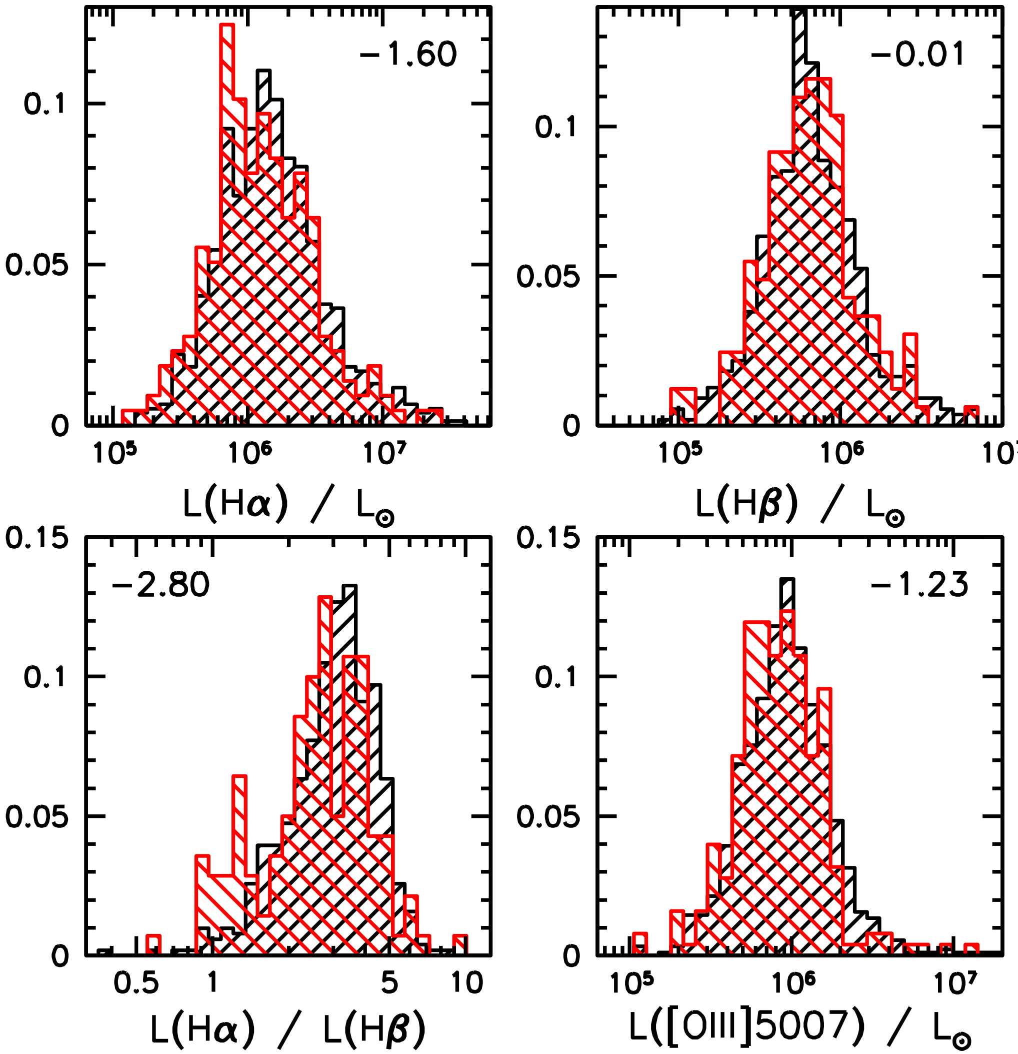


- old
- metal–rich
- α–enhanced



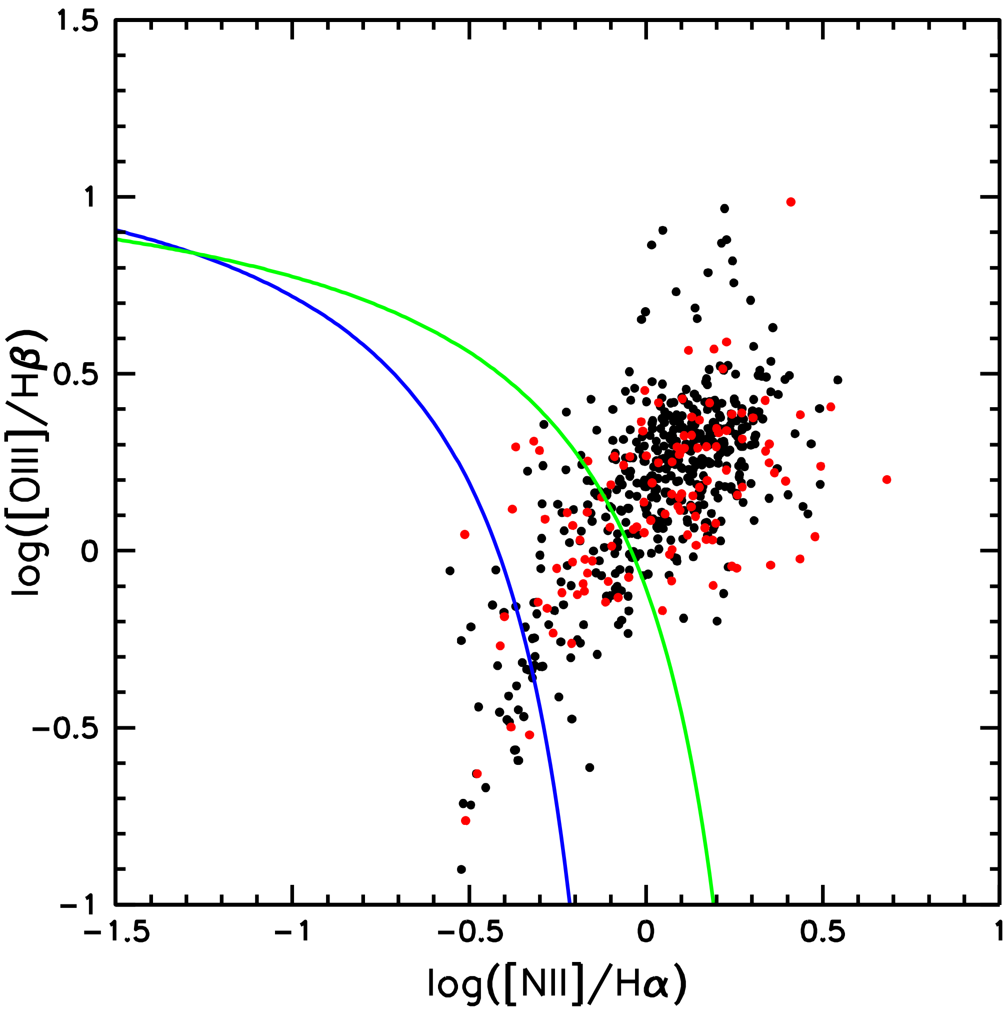
2
1.8
1.6
1.4
1.2
150
200
250
300
350
[Mg / Fe]
σ_v / km/s

Emission lines



- weaker in BCGs
- LINER–type

BPT diagram



6% star–forming
77% AGN
16% composite

6% star–forming
70% AGN
24% composite

Results

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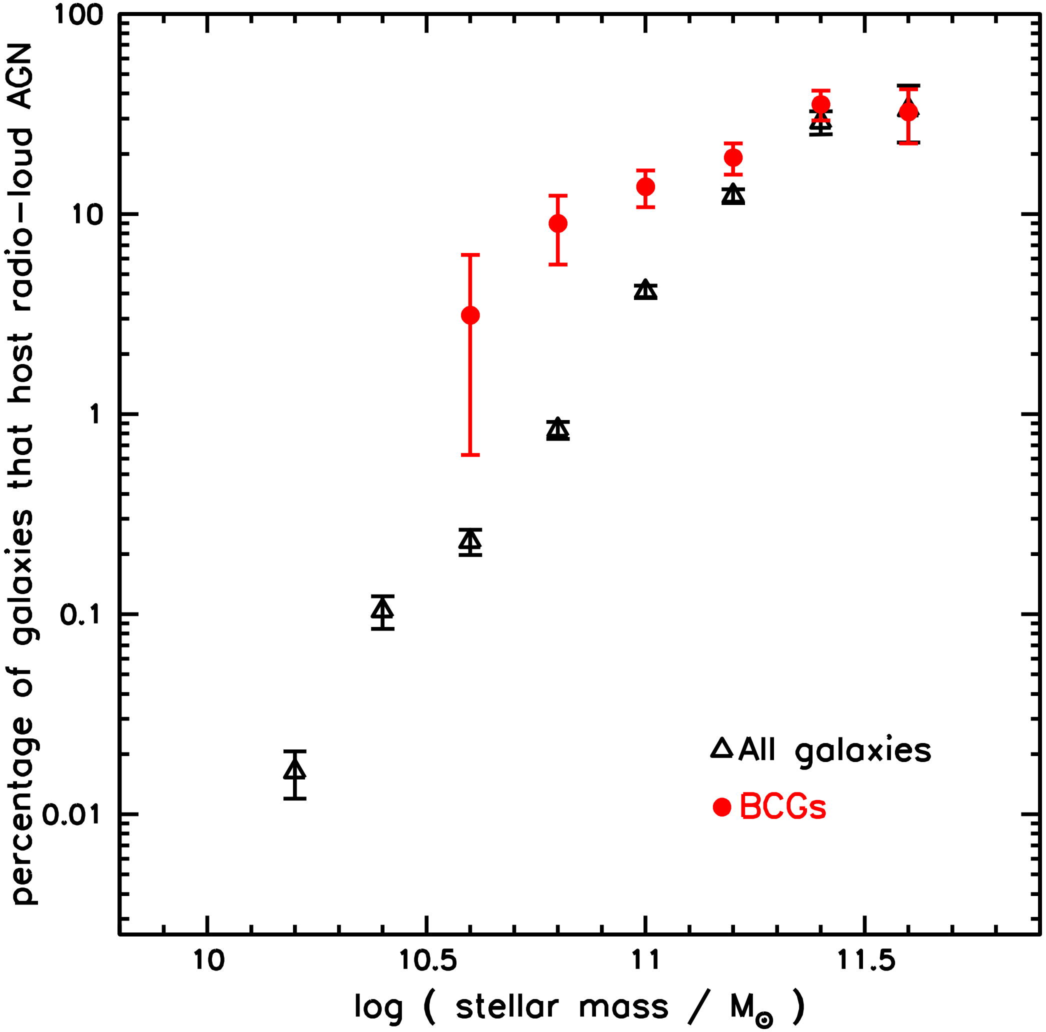
- lie on a different Fundamental Plane
- lie on a steeper Faber–Jackson relation
- **are more α–enriched**
- **have weaker emission lines**

. . . than non–BCGs

Results

- **BCGs are more likely to host a radio–loud AGN**



impact on cluster heating explored in Best, von der Linden, et al. 2006

Heating rates

- from Birzan et al. (2004) data:

$$L_{\rm radio} \longrightarrow L_{\rm mech}$$

- interpret radio–loud fraction and luminosity function probabilistically

$$\longrightarrow \text{time–averaged heating}$$

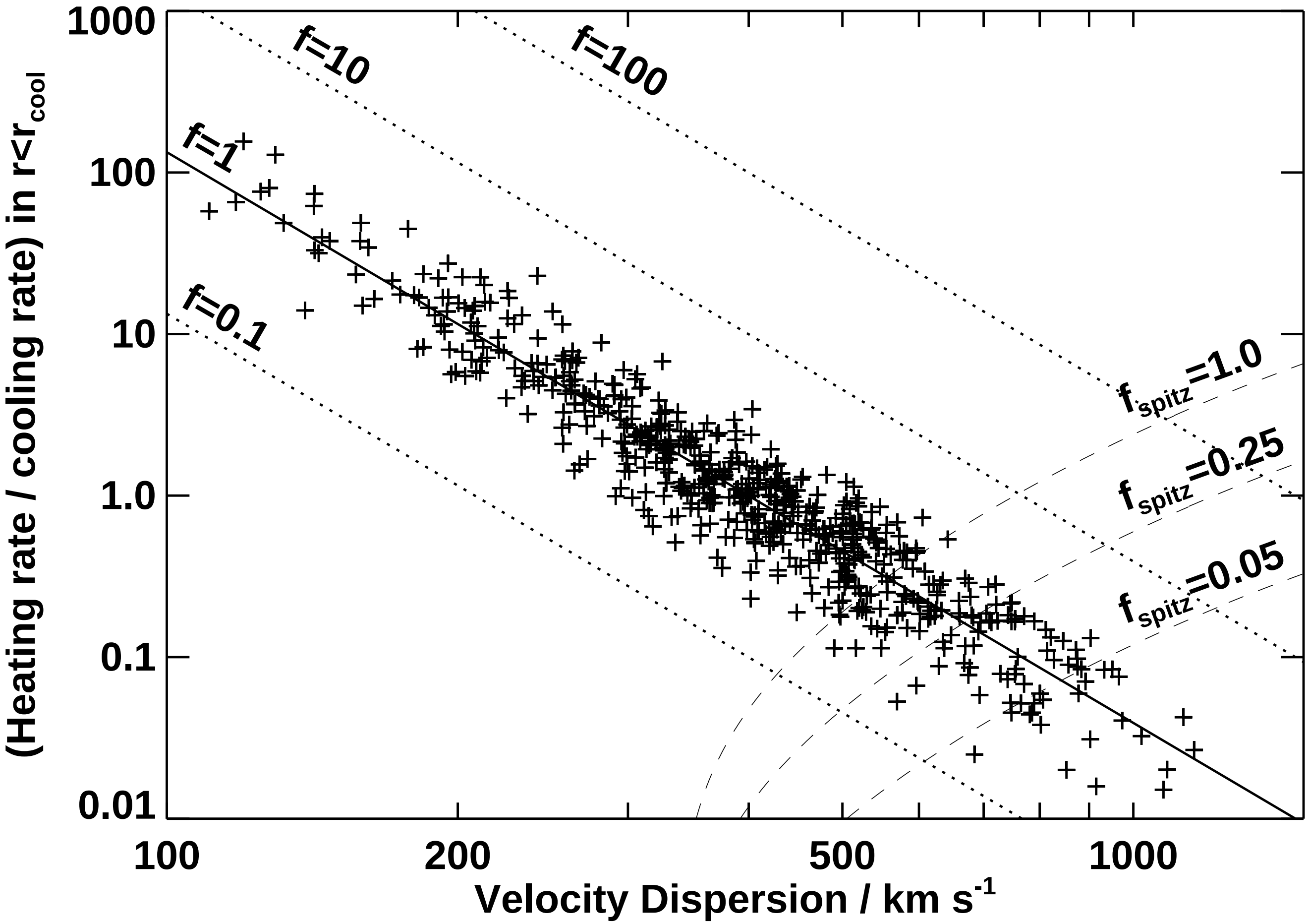
$$\bar{H}_{\rm BCG} = 2.3 \times 10^{35} f \left(\frac{M_\star}{10^{11} M_\odot} \right) \mathrm{W}$$

Cooling rates

- assume $\sim 25\%$ of L_{X} from within r_{cool} (Peres et al. 1998)
- with $L_{\mathrm{X}} - \sigma_{\mathrm{v}}$ relation:

$$L_{\mathrm{X}}(r < r_{\mathrm{cool}}) \approx 1.3 \times 10^{37} \left(\frac{\sigma_{\mathrm{v}}}{1000 \mathrm{km\ s}^{-1}} \right)^{4.1} \mathrm{W}$$

Heating vs. Cooling



over–heating in groups

heating not sufficient in richest clusters

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$\Rightarrow$ **BCGs are special!**